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THE SURFACE LAYER OF THE MOON

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ABSTRACT. Information on the Moon derived by astronomers is summarized. Data on the spacecraft sent to the Moon in the last eight years are given, starting with "Luna-1" in 1959 and including the American spacecraft in the "Lunar Orbiter", "Ranger", and "Surveyor" series.

The automatic interplanetary station "Luna - 1", which was launched on /3*
January 2, 1959, has become an artificial planet of the solar system. The conquest of interplanetary earth - moon space has thus begun.

These last eight years have represented a vigorous, astonishing epoch in the study of the moon. Year by year the trips of the automatic stations have placed new important information in the hands of scientists regarding the nature of the perpetual satellite of our planet. The greatest achievements on man's path to the moon have been the first soft landing on the lunar surface by the Soviet Automatic Station "Luna - 9" (Fig. 1), and the creation of the first artificial satellite of the moon, which became "Luna - 10".

The moon is never less than 356,000 kilometers from the earth. However, such distances are not great for our space age. The Soviet Automatic Station "Luna - 13" required 79 hours 44 minutes for the total flight. "Zond - 3" reached the vicinity of the moon after 33 hours with the intermediate orbit of an artifical earth satellite. It is interesting to recall that 30 years earlier, in June, 1937, the world record holders, Chkalov, Baydukov, and Belyakov, completed an unprecedented flight from Moscow- North Pole -America and were in the air 63 hours 25 minutes.

At the present time, there has been a rapid increase in research of the moon not only by space methods, but also by the customary methods of astronomy. Naturally, it is simply impossible to obtain the priceless information which automatic lunar stations transmit, from observations on the earth. However, systematic observations from the surface of the earth on the entire hemisphere of the moon have provided a stable foundation for generalizing the discrete cosmic data into an orderly system.

As a result of the combined efforts of "terrestrial" and "space" astronomers it has become apparent little by little that the traditional concepts of the lunar surface are very inaccurate. In the first place, this pertains to the unchanging nature of the "face" of the moon. A turning point was reached in the

*Note: Numbers in the margin indicate pagination in the original foreign text.

observations of N.A. Kozyrev and V.I. Yezerskiy on the night of November 2 - 3, 1958 on a 125 centimeter telescope at the Crimean Astrophysical Observatory of the Academy of Sciences SSSR. The spectrograms which they obtained with emission lines of a Svanov series of C_2 molecules, and also with a weak system of C_3 bands, indicated an outflow of gases in the region of the central peak of the crater Alphonse. Later, the reality of brief kurtoses on the lunar surface was confirmed by objective methods repeatedly. In this connection, the old, questionable visual data regarding movement on the face of the moon also were taken seriously.

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In the second place, at the present time, the concept of a completely uniform lunar surface fluctuates greatly. Finally, the problem of the "lunar dust" has again been raised. We should first of all state that the concept of fine, "talcum-like powder" and fluid "like flowing liquid", lunar dust is not upheld by all selenologists. In particular, N.N. Sytinskaya and V.V. Sharonov, in opposition to this concept, have advanced the well known meteorite-slag hypothesis. However, the term lunar dust is used too frequently. Just as in the debates on the delusions of the 18th century the erroneous hypothesis of Phlogiston is advanced, in the eyes of our descendents the lunar dust will represent an excellent example of the scientific illusion of the middle of the 20th century.

Today in the literature a modernized lunar dust is encountered. The opinion is advanced that the lunar soil is not dust, but is volcanic ashes, and not "magic castle" , and not "stony moss". In general, there is no analogy in human experience: On the surface of the moon there is a special state of matter which is intermediate between liquid and solid -- the infrasolid state. However, we /5 shall not go farther ahead and we shall attempt to briefly summarize what we presently know regarding the physical properties of the lunar cover.

The Astronomer at the Telescope

The possibilities for the astronomer-observer on the surface of our planet are greatly limited by the turbulence of the atmosphere, primarily at an altitude of several kilometers above sea level. Even under ideal conditions of mountain observatories, the most experienced observers can only observe visually those details of the lunar relief whose linear dimensions exceed 300-400 meters. Moreover, the atmosphere absorbs electromagnetic radiation having extraterrestrial origin of all wavelengths with two exceptions: Narrow atmospheric "windows" exist in the optical and radio range.

Nevertheless, by means of astrophysical observations, it was possible to form a concept of the microrelief of the lunar cover until that historic moment when the Soviet Automatic Station "Luna - 9" began its television transmission in the Ocean Of Storms initiating direct investigation of the lunar surface.

Photometric measurements were primarily used for this purpose for a long time. Innovating studies in the area of lunar photometry are connected with the well known Soviet astronomers V.G. Fesenkov, N.P. Barabashov, A. V. Markov, V.V. Sharonov. Their studies provided an impetus to the successful development of photometric lunar research in several Soviet observatories.

Measurements under differing illumination conditions have established the

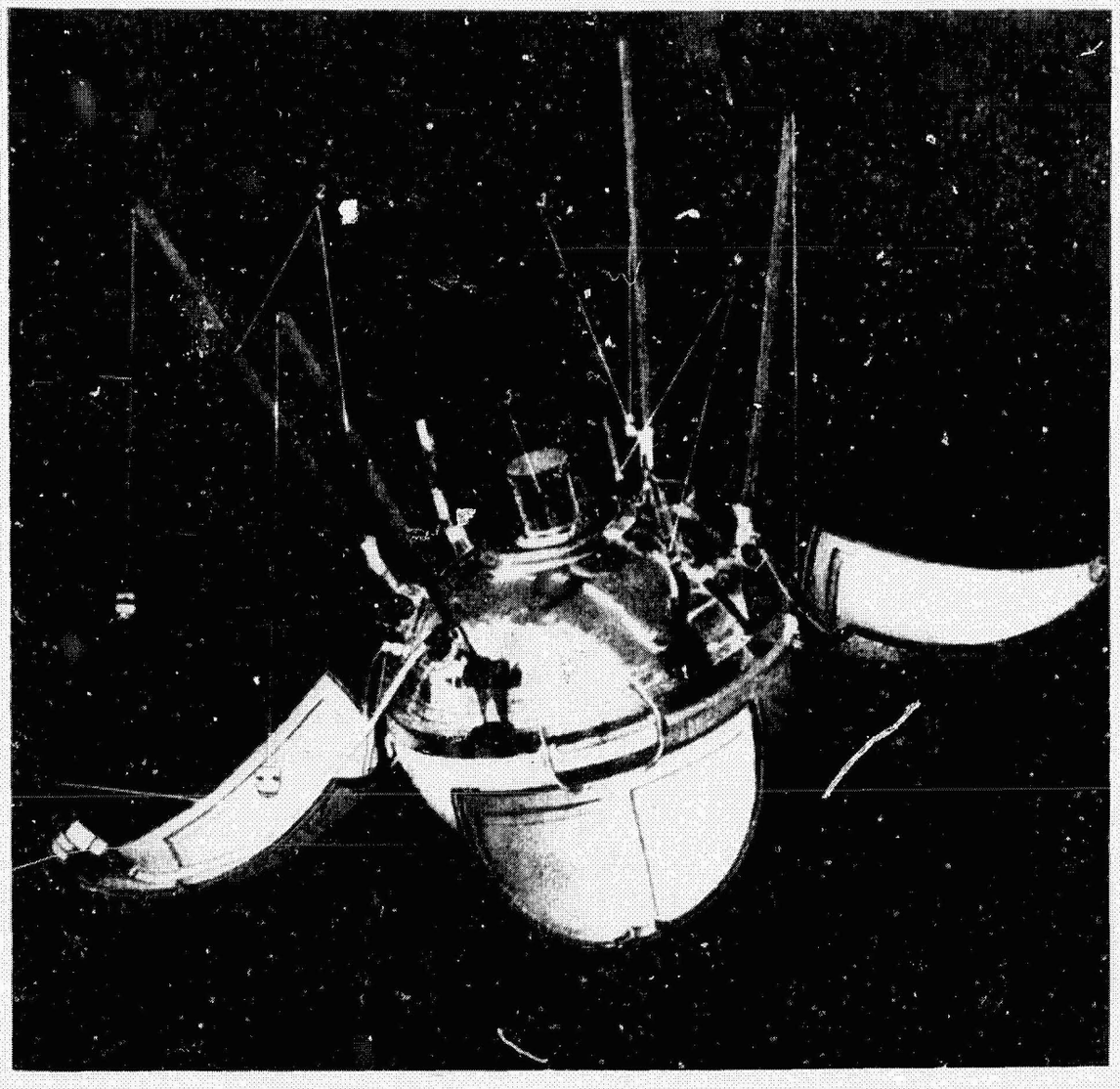

Figure 1. The Soviet Automatic Station "Luna - 9", the first in history on February 3, 1966, at 18 hours 45 minutes, 30 seconds, world time, to make a soft landing on the lunar surface. The following may be seen in the figure: 1 - Four lobe antennae; 2 - Four rod antennae; 3 - Brightness standards suspended on the rod antennae; 4 - Three dihedral mirrors for stereoscopic distance measurements; 5 - Panorama television camera. The dimensions of the spacecraft are as follows: From the base to the center of the television camera objective, 58 cm; height of the rod antennae, 112 cm; diameter of a circle passing through the open petals, 160 cm.

fact that the law of light reflection by the moon is very unique. The maximum amount of light is always reflected in the direction of the illumination source. The larger the angle of incidence of rays on the lunar surface, the larger the

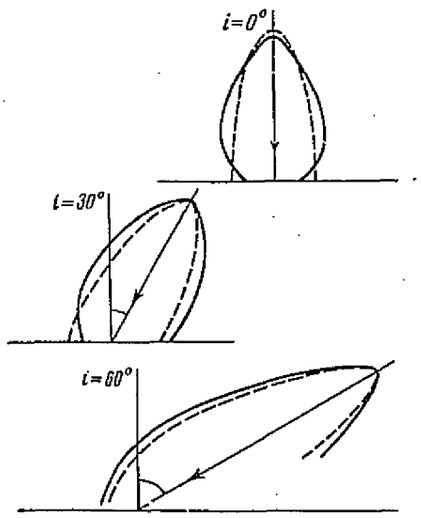

Figure 2. Scattering Indicatrixes for the Lunar Surface for Three Values of the Angle of Incidence of Light (i) (according to N.S. Orlov). The Solid Line Characterizes the Lunar Continents; the Dashed Lines designate the Lunar Seas.

relative extremal value. The scattering indicatrixes [1] for the lunar surface are shown in Figure 2 at different angles of incidence.

The photometric data definitely point to a rough, broken microrelief of the lunar surface, whose individual irregularities greatly exceed the wavelength of light (Figure 3). The high degree of porosity, and the jagged nature of the lunar surface are related to the corpuscular radiation, micrometeorite bombardment of the surface and sharp temperature drop.

The temperature of the lunar surface at a point underneath the sun reaches + 110° C (and even greater values, in the opinion of other authors), dropping at night to - 180° C before the sun rises. Similar temperature drops occur during the lunar eclipses (in terms of observations from the surface of the moon, they should be called "solar eclipses"). After the moon has left the shade, in less than one hour the surface temperature rapidly rises by almost 200°. It is assumed that these temperature gradients are sufficient for disintegrating rocks.

In this connection, it is of considerable interest to compare the fine structural characteristics of the surface layers of the visible and nonvisible hemispheres of the moon -- on the other side of the moon, where the earth never appears above the horizon, and there are no eclipses. This comparison could throw light upon the reasons for the enormous differences between them, which have been determined by the Soviet Automatic Stations "Luna - 3" and "Zond - 3". Subsequently, the same phenomenon was substantiated by photographs of the /6
American satellites in the "Lunar Orbiter" series. It is of great importance to determine whether the observed differences between the visible and nonvisible hemispheres are directly connected with the influence of the earth, or whether this phenomenon is accidental.

The significant temperature drops, observed on the lunar surface, indicate low heat conductivity of the lunar soil.

Most of the energy of the solar light falling on the lunar surface is absorbed and re-admitted in the infrared region of the spectrum. R. Shorthill and J Saari have made fruitful investigations in recent years of the thermal properties

1. A curve showing the distribution of the scattered light in different directions.

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Figure 3. Structure of the "Magic Castle" . Interpreting the Photometric Data, in 1963 Van Horn and Khapke proposed a Model for the Lunar Surface with a Structure which has received the Name Of "Magic Castle". In their Opinion, the Finely Granular Substance of the Lunar Soil, after being Cemented Together, Forms Very Large (as Compared with the Granules themselves), odd-shaped porous clusters. The Photograph shows the Large-Scale Model of the Structure Proposed by Khapke and Van Horn. During lateral illumination, the individual, irregular forms of "soil particles", and the odd-shaped honeycomb of the "magic castle" formed by them are clearly visible.

of the visible hemisphere of the moon by observations in the infrared regions. They have determined a large number of points whose temperature during the eclipses remains 10°higher than the temperature of the surroundings. The thermal regions coincide with centers of systems of rays and other new formations.

Based on present-day estimates, the density of the hypothetical lunar atmosphere probably amounts to 10^{-12}, and in any case no more than 10^{-10} of the terrestrial atmosphere density at its base. Thus, the moon is practically devoid of a protective gas covering, and the interplanetary space surrounding it by no means contains a great number of ingredients. The main phenomena influencing the lunar surface, as a result of its direct contact with interplanetary space, are micrometeorites, and also ultraviolet radiation along with solar corpuscular and primary cosmic rays.

In one of the numerous experiments carried out recently, the influence of the "solar wind" on a simulated lunar surface was modeled by intense bombardment with helium ions having energies of 1-20 kev. This bombardment had a significant influence upon the physical and chemical structure of the surface. The surface was rapidly covered with a baked, brittle crust and -- in the case of

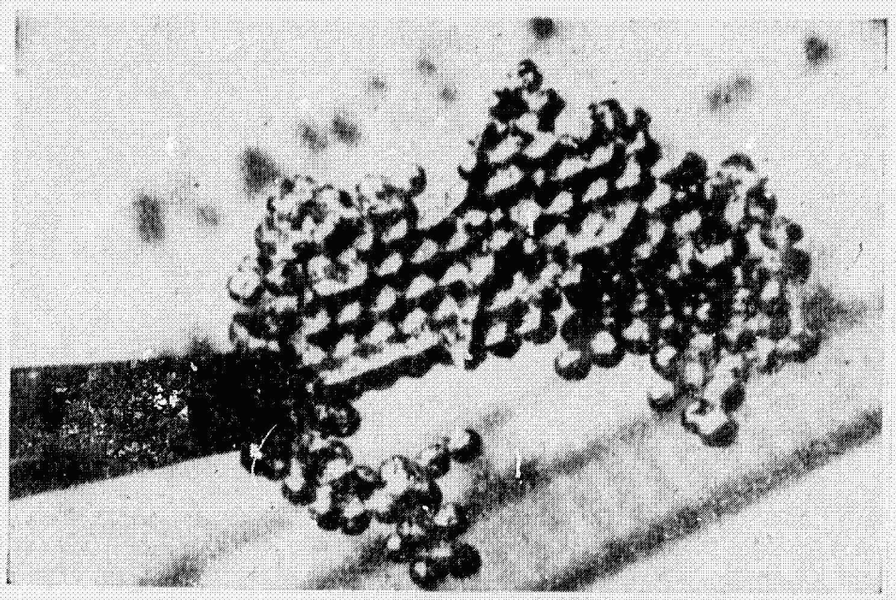

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Figure 4. Steel Balls having a Dimension of 0.75 mm Adhering Together as the Result of Bombardment by Mercury Ions with an Energy of 500 eV. As may be seen, the Structure Produced is so Solid that it can be Picked Up with Tweezers.

oxides -- was greatly enriched with free metals. The bombardment led to an increase in the rough nature of the polished surface and, on the other hand, it smoothed out the roughness (Figure 4).

The surface of the moon is dark. The albedo serves as a quanitative characteristic in this respect, i.e., the ratio of the brightness of the surface being studied to the brightness of an absolutely white surface under identical illumination conditions. The data on the albedo of certain objects on the earth and details on the moon are given in Table 1.

On the average, the moon reflects only 7% of the light falling upon it. As may be seen from Table 1, the brightest location on the moon (the crater of Aristarchus) is only 3.5 times brighter than the dark lunar seas. /7

The small brightness of the lunar surface, as well as the roughness, is frequently related to corpuscular radiation. Experiments have shown that the bombardment by ion beams has a considerable influence on the albedo and color of the rocks which are irradiated, which become dark.

With respect to the color contrasts on the moon, its surface is undoubtedly very monotonous. However, even the small hues of color make it possible to draw far reaching conclusions. The colored regions on the moon have sharp boundaries which definitely serves as an argument against lunar dust, since a thin layer of it would tint these boundaries.

Polarization studies of the lunar surface, as well as photometric studies, could be interpreted in such a way that the surface is composed of an agglomerate powder made of opaque grains.

TABLE 1

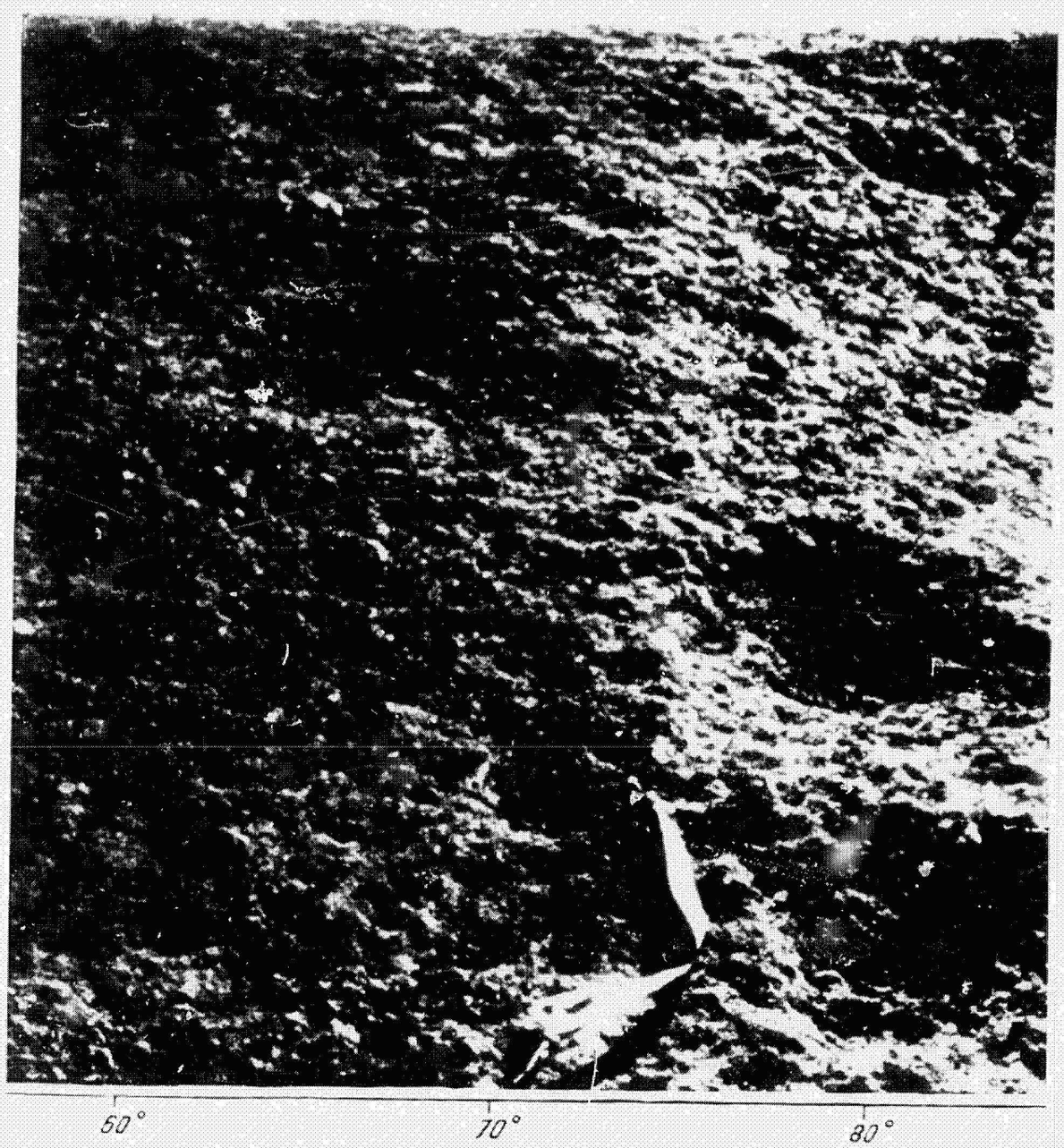
COMPARISON OF THE ALBEDO OF CERTAIN FORMATIONS ON THE EARTH AND DETAILS ON THE LUNAR SURFACE

Earth	Snow	0.9--0.5
	Sand	0.34--0.29
	Granite	0.24
	Stony meteorites	0.18
	Chernozem	0.05--0.07
Moon	Aristarchus (very light formation)	0.176
	Sinus Medii (very dark formation)	0.054

With the development of radar observations, it has been established that millimeter waves are scattered very greatly by the moon. Centimeter and longer waves are reflected as though the lunar surface consisted of smooth ground (no less than several meters) randomly inclined to the horizon within tens of degrees. Based on these data, the roughness of the lunar surface does not exceed several millimeters on the average, and the density of the substance comprising the surface is low.

It is well known that seismic waves are employed to study the depths of the earth. These waves, "transmitting" to our planet, make it possible to establish the boundaries between layers of differing density. In this way the boundary of the Wieghert-Gutenberg discontinuity, the surface Mohorovičić, and others were discovered. Radio waves play a similar role to a certain extent in investigations of the moon. Due to the nonidentical absorbtion, radio waves of different length arrive from different layers of the moon, and the longer waves come from the deeper layers. The moon which is nontransparent for the visible and infrared radiation, becomes partially transparent in the region of centimeter waves. /8

In research on the eigen radio emission of the moon, the fundamental fact has been established that the amplitude of the daily variation in temperature, derived from observations in the radio range, is less than the amplitude measured in visible light, and decreases with an increase in the wavelength. This fact may be interpreted in one way: the surface layer of the moon has an extremely low thermal conductivity. Based on calculations in CGS units, the thermal conductivity coefficient of lunar rocks is $3 \cdot 10^{-6}$; dust in a vacuum has a coefficient on the same order.



One of the Fragments from the Third Panorama -- Section of the Lunar Surface to the East of the Point where "Luna - 9" landed; Width of the Film in the Foreground is 13 Millimeters; Distance of the Details close to the Upper Horizontal Frame of the Fragment -- about 2 1/2 Meters from the Base. (From the Book "Pervyye Panoramy Lunnoy Poverkhnosti" (First Panoramas of the Lunar Surface), Izdatel 'stvo "Nauka", 1966 .

Above: Examples of Linear Structures in the South Eastern Section of the Third Panorama, Transmitted from "Luna - 9"; a, b - Linear Structures Intersecting the Craters-Pits (Horizontal Boundaries of the Fragments are Parallel to the Direction of the Structures; c - System of Mutually Intersecting Linear Structures (To the Left Above, may be seen a Bulge with a Depression in the Central Section); d - Fragment "c", Changed to a Horizontal Plane); e - Another Type of Linear Formation; To the Left of the ALS a Depression May be Seen Which is Similar to a thread-like Groove; f - "Laminar" Structure (Parallel to the Horizontal Edge of the Fragment).

Above: Fragment of the Panorama of the Lunar Surface Transmitted from the ALS "Luna - 13" December 26, 1966 when the Sun was about 19° above the Horizon. Certain Details of the ALS may be seen on the Fragment.

The eigen radio emission of the moon has been studied very greatly in recent years in the Scientific Research Radio Physical Institute of the Gor'kiy University imenii N.I. Lobachevskiy. Professor V.S. Troitskiy and his coworkers have studied the nature of radio emission of the moon in a wide range of waves with a wave length from 0.1 to 70 cm. According to their data, the uppermost very porous layer is about 3 - 4 cm thick. Its density comprises 0.5 of the density of water, and the electrical conductivity is 1.5 - 2 times greater than the electrical conductivity of bedrock. Below the surface "crust" there is a layer which is 6 - 8 meters wide, whose density approaches the density of water. The substance comprising this intermediate layer, just like that comprising the upper layer, occurs in a very porous state. Lunar "rocks" lie below.

Radio astronomical data have one serious disadvantage; they characterize only the average values of the quantities desired over enormous areas. Due to this fact, they must be utilized with a certain amount of caution. As was already indicated above, at present few individuals insist on the complete uniformity of the lunar surface.

Sublime Desolation

All authorities agree that to messengers from the earth, the lunar surface would be a gloomy and inhospitable area, representing an example of "sublime desolation" -- a dazzling sun; dark, lifeless spaces; sharp, thick shadows, and a dark sky overhead.

In many studies, particularly those published recently, the low atmospheric density and the lack of a hydrosphere on the moon are explained by the fact that its surface layer had not been destroyed. Due to this fact, opinions have been advanced regarding the recent, unchanged surface of the moon, containing those magmatic rocks which lie in the upper layers of the lunar crust. In the opinion

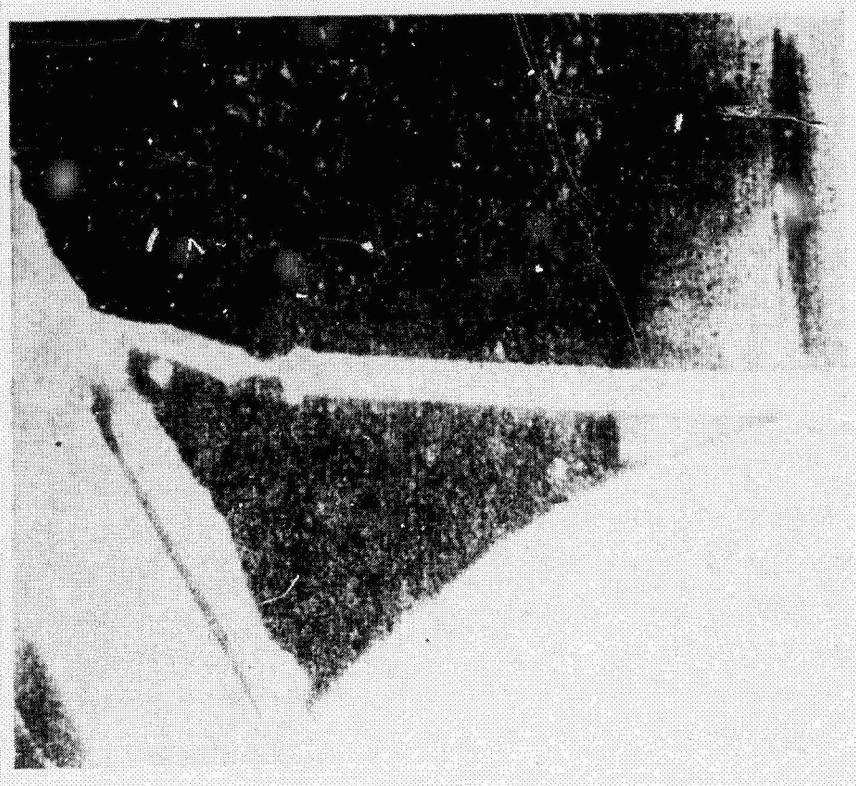


Figure 5. Lunar Soil Underneath Spacecraft "Surveyor - I". In the Upper Left Corner of the Frame, A Crack may be Seen which was Caused by the Impact of the Control Shock Absorber Number 3 (See the Diagram in Figure 6). Based on Measurements of the Dark Area, the Depth of the Crack Produced is 2 Centimeters. The Detail of the Apparatus in this Frame were not Developed, and Look Like Light Spots.

of the adherents of this opinion , the lunar landscape represents a random accumulation of rocks and scales, alternating with cracks and troughs. The differences in the albedo of the seas and continents is regarded as a real difference in the components of the surface rocks.

On the basis of polarimetric measurements, in 1929 Leo advanced the hypothesis of volcanic ash. Later, theoretical calculations of the effectiveness of micrometeorite bombardment and the influence of the "solar wind" led to the concept of lunar dust. In 1948, Vesselink elaborated upon this problem. Thomas Gold became an apologist of lunar dust. In particular, he stated that plains on the lunar seas were not fields of frozen lava, but basins filled with dust -- the layer of which amounted to several kilometers. Observational facts (the absence of a dependence between the coloration and curvature of mountain slopes, the sharp boundary between the dark surface of the seas and the light slopes of the mountain ranges bordering upon them, etc.) led Gold to attribute an unusual fluidity to the lunar dust.

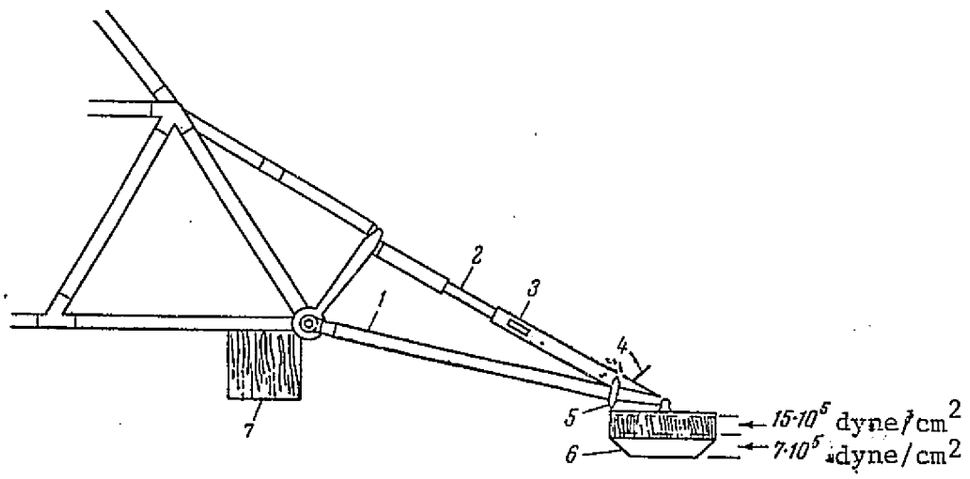


Figure 6. Diagram of the Landing Support of Spacecraft "Surveyor - 1"; 1 - Mechanical "leg"; 2 - Hydraulic Shock Absorber of the Aircraft Type; 3 - Load Sensing Element; 4 - Photometric Scale; 5 - Impeller of the System for Controlling the Position in Space; 6 - Supporting "Shoe" made of Collapsible Aluminum Honeycomb Panels; The Outer Layer of the "Shoe" in the Form of a Frustum of a Cone Supports a Load up to $7 \cdot 10^5$ dyne/cm^2; the Inner Layer of the "Shoe" Supports a Load Up To $10 \cdot 10^5$ dyne/cm^2; 7 - The Cylindrical Control Shock Absorber Made of Honeycomb Panels for Preventing a Sharp Impact by the Spacecraft, Designed for a Load of $30 \cdot 10^5$ dyne/cm^2.

However, the authors advancing the hypothesis of lunar dust neglected the phenomenon of adherence which is well known in physics. For specialists on the Earth, adherence is a reliable method for solving a great many technical problems: the depositing of components by "optical contact", the creation of composite gauges by building up several terminal gauge blocks, etc. A special case of adherence is the cohesion of different solid bodies upon contact -- which is called adhesion. Since the role of the Van der Waals attractive forces increases greatly under the conditions of an extensive lunar vacuum, the phenomenon of adhesion inevitably influences the formation of the lunar microrelief.

The most valid system of opinions on the nature of the lunar surface was developed in the Astronomical Observatory of Leningrad University by N. N. Sytinskiy and V. V. Sharonov. According to their opinions, exogenic factors, and not endogenic, play a decisive role in the formation of the landscape. In their opinion, a considerable amount of thermal energy, which is liberated upon /9 the impact of meteorites, can stimulate chemical reactions, leading to the formation of minerals with a low albedo. The material which is volatilized during the eruption settles and adheres to the surface. A mass which is baked, porous, and fairly strong, is one product of this phenomenon. As examples on the Earth, the authors pointed to volcanic cinders, calling the material on the lunar surface "meteorite cinders". In this connection, this system of opinions advanced by the Leningrad scientists, which was developed by several other Soviet researchers, was called the "meteorite-cinder hypothesis".

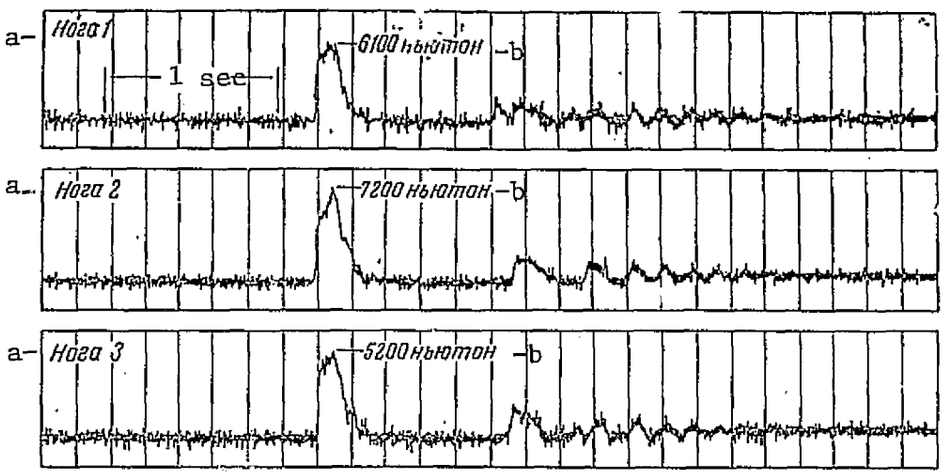


Figure 7. Traces of the Dynamic Loads on the Landing Supports During the Landing of the Spacecraft "Surveyor - 1". The Apparatus was Braked Initially by the Main Retrorocket, and Later by Three Vernier Liquid Engines. The Latter were Shut Off at an Altitude of 4 Meters at a Velocity of 1.5 m/sec. Continuing to Fall, "Surveyor - 1" Touched Down Upon the Moon with a Vertical Velocity Component of 3.5 m/sec, and a Horizontal Velocity Component of 0.3 m/sec. The "Feet" of the Landing Gear Touched the Surface Almost Simultaneously Within 0.01 Seconds (The Main Peak in the Trace). The Loads along the Axes of Each of the Three "Feet" Comprised 6100, 7200, and 5200 Newtons at Impact (Newton = 10^5 dyne), which Correspond to Loads of 1900-2200 Newtons, or From 4.10^5 to 7.10^5 Dyne/cm^2, on the Horizontal Plane of the Supporting Shoe. After the First Contact, the Body of the Spacecraft Settled Sharply, and the Control Shock Absorbers on the Bottom were buried into the Ground. After this, the Spacecraft Jumped into the Air to a Height of 6 Centimeters, and Approximately 6 Seconds after the First Contact it Again Settled on the Surface (The Second Peak of the Trace). During the Second Impact, the Loads were 4 Times Smaller than During the First Impact. Several of the Subsequent Peaks Pertained to Wobbling of the Spacecraft. (a) - leg; (b) - newton.

First with the Eyes of the Cosmonaut

On February 3, 1966, an event took place which ranks along with such achievements in space as the launching of the first artificial Earth satellite and the first flight of a manned spacecraft: in the Ocean of Storms, at a location having the coordinates of 7°08' north latitude and 64°22' west longitude, the Soviet "Luna-9" made a soft landing. If the last frames made by the American "Ranger" probes had a resolution which was 10^2 - 10^3 times better than the photographs obtained from the Earth, then a panorama of the lunar landscape was transmitted from "Luna-9" whose resolution was 10^2 - 10^3 times greater than in the

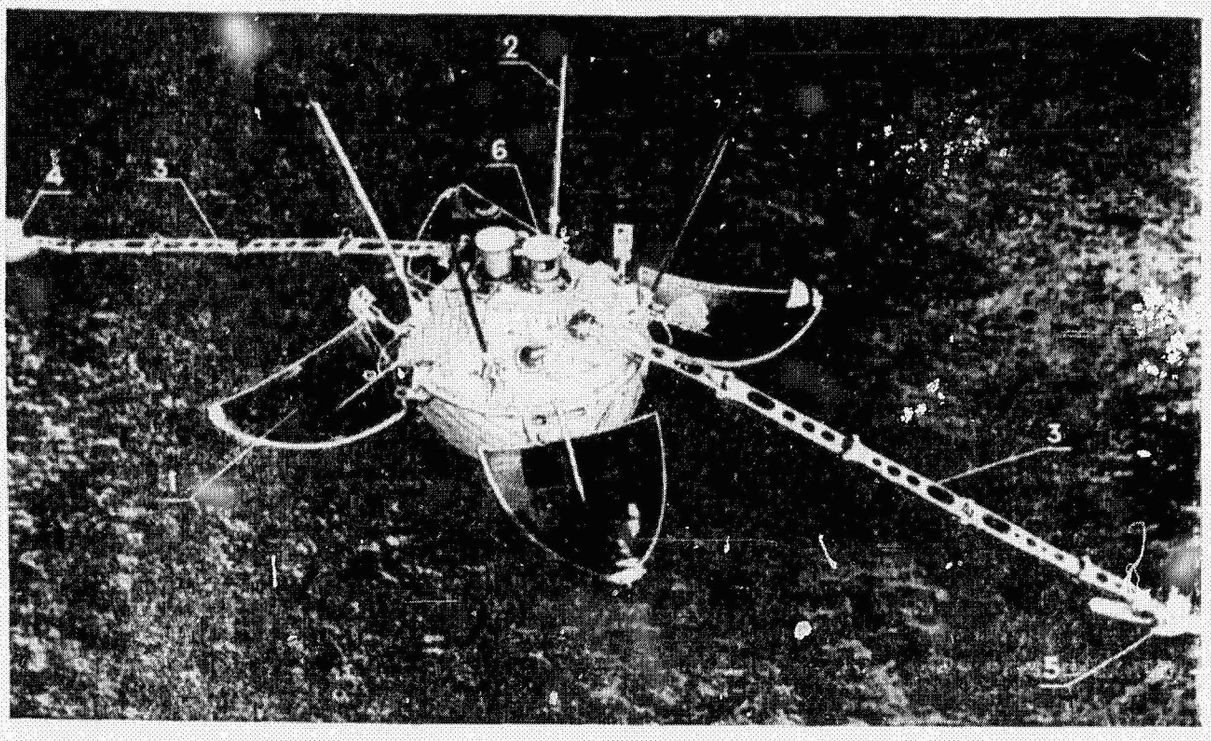


Figure 8. Soviet Automatic Station "Luna - 13", Which made a Soft Landing on the Ocean of Storms on December 24, 1966, at 18 Hours 01 Minutes World Time: 1 - Lobe Antenna; 2 - Rod Antenna; 3 - Mechanism for Extending the Devices; 4 - Mechanical Soil Density Meter; 5 - Radiation Density Meter; 6 - Television Camera.

telephotographs of the "Rangers". Details which are millimeters in size may be seen in the panorama.

As a result of the soft landing of "Luna-9", an avalanch of new data has been placed in the hands of selenologists. The landing itself was of tremendous value -- it was an irrefutable proof of the correctness of the engineering calculations and the theoretical computations of the people who constructed it.

The homogeneity of the lunar surface was established in the panorama photographs. This conclusion was definitely substantiated by the subsequent landings of "Surveyor-1" and "Luna-13". Not one of the components of the station was covered with dust. The high quality of the image also indicated that the objectives of the telesystem were clean. Nowhere on the panorama was a structureless dust layer seen; the lunar soil was solid. Based on the telephotographs obtained during a supplementary communication period on the night of February 6 - 7, the angles of inclination for decimeter holes, within which shadows were visible, exceeded 41°.

As a result of studying the panorama photographs of "Luna-9", the overwhelming majority of selenologists definitely rejected the concept of "lunar dust".

The following three types of details are characteristic for the lunar surface:

-- Craters-holes, or cones, with scarcely noticeable ridges, and sometimes without ridges;

-- Extended linear structures;

-- Stones.

As was assumed previously, negative forms of the relief predominate on the lunar surface -- craters-holes, depressions, cracks. One new fact was discovered -- linear structures which have predominant directions. In several cases, the intersection of the craters-holes with the linear structures was cle rly apparent. Apparently, the strength of the linear structures is higher than the strength of the material surrounding them. It is possible that these structures represent the outcropping of small veins which are very stable when the surface rock is destroyed.

Bedrocks belong to the linear structures. It is hardly accidental that the azimuth of the most clearly expressed bedrock coincides with the predominating direction of the "vein" linear structures.

The panoramas make it possible to estimate the number of positive forms on the relief -- blocks and stones; about 150 of them were discovered over an area of 50 m^2.

On the whole, forms of the lunar microrelief were definitely related to erosion exogenic processes. The negative balance of masses for the location where "Luna-9" landed indicated the following: the mass of particles falling on the surface is less than the mass of substance leaving it. Apparently, there is a negative balance of masses on the entire lunar surface.

A study of the "Luna-9" panorama showed that the formation of the lunar surface was definitely not due to just one process. In conformity with the macrorelief of the visible hemisphere of the Moon, the well-known Soviet selenologist A. V. Khabakov has subsequently advanced this viewpoint.

As a result of studying the extent to which rocks were scattered on the telephotographs of the "Ranger" spacecraft, J. Kuiper reached the conclusion that the strength of the lunar soil is $1 \cdot 10^{-2}$ or $1 \cdot 10^{-3}$ the strength of basalt, i.e., it can sustain a load on the order of 1 - 10 kgf/cm^2 (0.001 - 0.01 n/m^2).

Yu. N. Lipskiy made similar computations based on the panorama photographs /10 of "Luna-9". He also showed that the surface of the Moon sustains a load of several kgf/cm^2.

The photographic reconnaissance of the lunar soil, performed by "Luna-9", determined the pattern and basic directions of subsequent experiments.

June 2, 1966, four months after the landing of "Luna-9", the Ocean of Storms, close to the Flamsteed Crater, became the landing place for "Surveyor-1". The space probe, whose flight was delayed by three years and whose cost exceeded the planned cost by a factor of 10 -- more than 500 million dollars -- landed at a point with the coordinates 43°, 32 north longitude and 2°, 49 south longitude.

In spite of the fact that the point where "Surveyor-1" landed was 800 kilometers from "Luna-9", the microstructure of the surface was completely similar to that already described. The ground close to the spacecraft had a homogeneous structure with small lumps -- this was a granulated material with grains whose sizes varied greatly (Figure 5). Particles with dimensions of no more than 2 millimeters were the most typical. However, the size of the initial grains was less than the resolving power of the television camera. The connection between the size of the lumps and stones and the number of them per 100 m^2 was approximated by the formula $N = 3 \cdot 10^5 \cdot y^{-1.77}$, where N is the total number of formations whose dimensions are greater than y in millimeters. The formula is valid for $1 < y < 2000$ mm. The estimates were made for 825 objects.

An analysis of the traces of the landing (Figure 7) shows that the surface of the Moon is solid, and its mechanical properties are similar to the moist terrestrial soil which is slightly granular. It is possible that above the solid soil there is a surface layer 2 - 3 centimeters thick which adheres together, but is less solid than the surface layer. These results coincide closely with the opinions of V. S. Troitskiy. The data derived from the landing of "Surveyor-1" are insufficient for making a definite calculation of the limiting permissible static load on the soil. However, it comprises no less than 0.4 kgf/cm^2 according to rough estimates.

In order to verify the concept of the "dust covering", "Surveyor-1" performed an experiment in which the surface was blasted for a short period of time with a stream of nitrogen. The jet engine of the control system, which was located on the landing support No. 2, placed at a 72° angle at a distance of 12 centimeters from the surface, was switched on in pulses for 20 microseconds, with pauses of 30 microseconds for a period of 12 seconds. It developed a thrust of 0.028 kgs. The location where the blast took place was photographed. No "dust cloud" or any other anomalies were observed after the apparatus was switched on. Only a small cone-like crater was observed at the point where the blast took place. However, the television photographs taken before the experiment did not make it possible to answer the question of whether it existed previously or not.

At the beginning of 1966, the Soviet scientists achieved still another great success: they were the first to plan and successfully carry out, not an indirect but a direct determination of the physico-mechanical properties of the/11 lunar soil at the landing point.

The landing point for "Luna-13" (Figure 8) was again the dark plain of the Ocean of Storms. Launched on December 21, 1966, the automatic station "Luna-13" reached the surface of the Moon December 24, at 18 hours 01 minutes World Time, completing a soft landing in a typically "sea" region at a point where the

coordinates 18°52' north latitude and 62°03' west longitude near the craters of Krafft, Selevk, and Schiaparelli. The landing on the Moon was made in the pre-morning "hours" of the lunar day in the light of a narrow crescent of the Earth. The landing place was quickly illuminated by rays from the Sun.

In addition to the phototelevision unit, "Luna-13" carried an entire laboratory on-board for testing the strength and density of the lunar covering. In- /12
cluded among the equipment carried by the spacecraft were a measuring penetrating-soil density meter, a dynamograph, and a radiation density meter.

The measuring, penetrating soil density meter -- or, as such devices are usually called, a penetrometer -- is in the form of a rod with a conical tip. A special device for extending the soil density meter -- a mechanical "hand" -- extends it to a given distance from the spacecraft body. The conical tip is introduced into the ground by means of a small jet engine which develops a fixed thrust of 7 kgf in 1 second.

The duration and magnitude of the dynamic overload pulse when the automatic station contacted the lunar surface was recorded by the dynamograph, consisting of piezoelectric sensors and an electronic memory system. The dynamograph makes it possible to compare the characteristic features of the "Luna-13" landing with the dynamic data of model experiments conducted under conditions on the Earth. The comparison led to the conclusion that the upper layer of the lunar covering, which is 20 - 30 centimeters thick, has approximately the same mechanical indices as terrestrial soils having average density.

If the data on the dynamics of the landing provided a basis for estimating the strength of the soil, then the requisite information on its density was collected by means of a radiation density meter (Figure 9). It consists of a small radioactive source of gamma-radiation and three units of gas discharge counters of gamma quanta. A protective screen, mounted between the source and the counters, protects the counters from the direct incidence of gamma quanta, so that they record only scattered radiation. The intensity of the scattered gamma-radiation attained by the gas discharge counters is a function of the density of the scattering surface. According to preliminary reports, the den- /12
sity of the outer layer of the lunar crust does not exceed the density of water.

Telephoto information received from "Luna-13" substantiated the basic conclusions of Soviet scientists which were reached by analyzing similar information from "Luna-9": the destruction of the lunar crust plays a decisive role in the formation of the microrelief. There is also a negative mass balance in the region studied.

Just like the panorama of "Luna-9", the television pictures of "Luna-13" disclosed numerous craters-holes, rocks of different sizes lying on top of the ground, and nonlinear structures which were vein-like in nature.

In April-May of this year, the mechanical properties of the lunar surface were studied by the automatic station "Surveyor-3", which was launched April 17. On the third day of flight it landed at the equator close to the crater Landsberg. The spacecraft was equipped with a miniature scoop, which made it possible

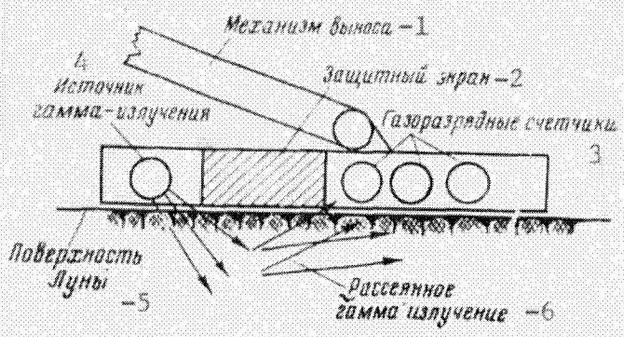


Figure 9. Principal Diagram of the Radiation Density Meter Carried On-Board the Soviet Automatic Station "Luna - 13".

(1 - Extension Mechanism; 2 - Protective Screen; 3 - Gas Discharge Counters; 4 - Source of Gamma Radiation; 5 - Surface of the Moon; 6 - Scattered Gamma Radiation).

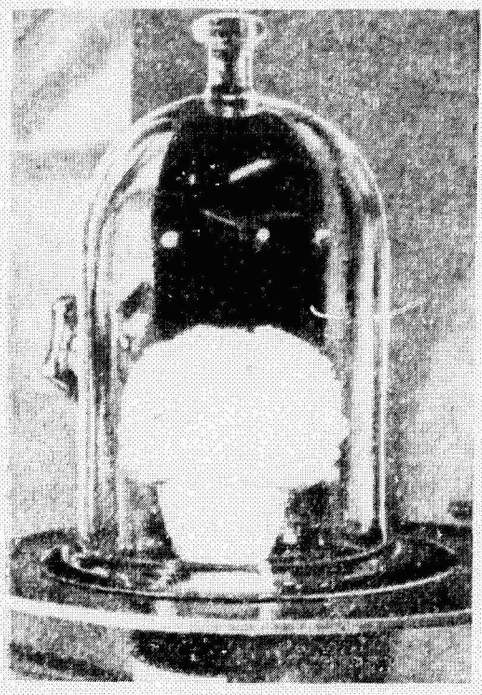


Figure 10. Artifical Mineral *Simolivac* (Abbreviation from the English Silica Molten in Vacuum), which is Unknown in Geological Practice, was Obtained by Walter Dobar and His Co-Workers by Cooling a Melt of Silicon Dioxide SiO_2 in a Vacuum. The Initial Sample (Either Sand or a Block of Flint Glass) with a Volume of 50 ml was Melted in an Electric Oven at a Temperature of 1500 Degrees C. The Sample Remained in the Melted State at Atmospheric Pressure for 1 Hour. Then the Crucible with the Melt was placed in an Hermetic Jar, which was Connected with a Large Vacuum Chamber. Opening of the Valve Led to Sharp Decompression under the Jar; the Pressure fell from Atmospheric Pressure to 0.4 mm Hg. The Sample Frothed and Solidified in the Form of a Stony Sponge whose Volume Exceeded the Initial Sample by 15 - 20 Times. The Mean Density of the Simolivac was 0.12 g/cm^3. Its Strength Fluctuated Greatly: from 1.2 kgf/ cm^2 for a Simolivac made of Flint Glass up to 4.5 kgf/cm^2 for a Sand Simolivac. Gamma Radiation for 94 Hours (4.37×10^6 r.) Changed the Optical Properties of the New Mineral Somewhat. There is Almost Complete Agreement between the Photometric Curves of the Simolivac and the Lunar Surface. The Minerals Batolivac and Grantolivac were Later Obtained by the Same Methods from a Base of Basalt and Granite. Their Strength Fluctuated from 1.5 to 7 kgf/cm^2.

to dig up and move small amounts of soil. According to reports which have been received, the data indicated that the dry granular lunar soil is similar in consistency to wet sand under conditions on the Earth. There have been new indirect indications of the small thickness of the surface layer. Based on certain indications, the scoop of the spacecraft reached an intermediate, harder layer close to the surface.

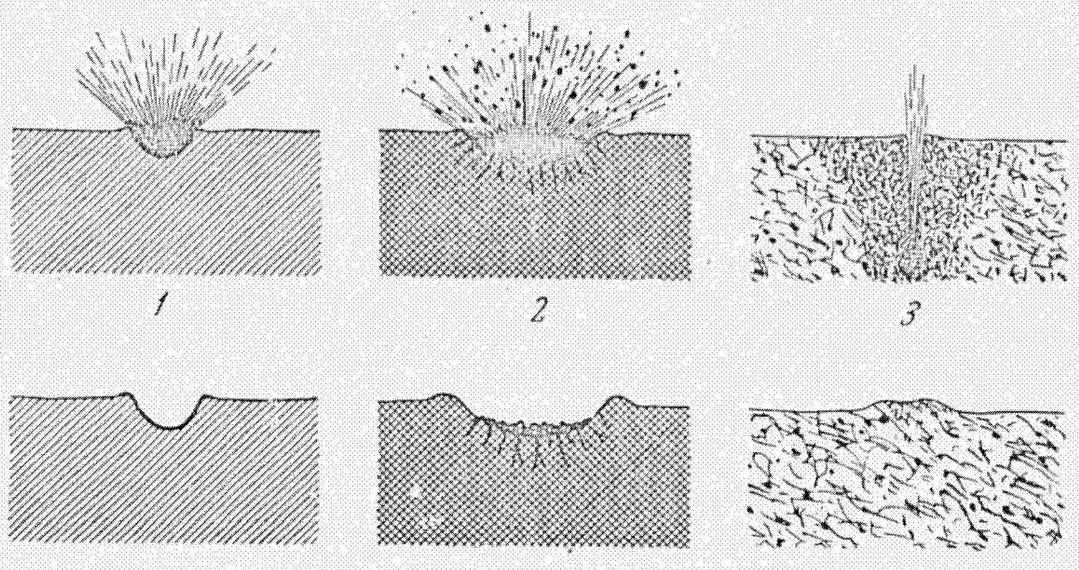


Figure 11. Simulation of the Forms of Impact Craters by High Velocity Bombardment of Different Targets: 1 - Metal; 2 - Basalt; 3 - Dendroid Target.

Hand Made Lunnites

In recent years, modeling has become one of the most powerful methods of studying the features of the lunar soil. It has been done in several ways. Previously, scientists attempted to imitate the processes, leading to the formation of minerals of the lunar surface. The experiment of Walter Dobar was an example of this modeling: the cooling of silicon dioxide melt in a vacuum chamber (Figure 10).

However, most frequently conditions on the lunar surface are simulated in another way. In the simplest models of connected, unconnected, compressed and noncompressed soils, the influence of the lunar medium characteristics is tested: a hard vacuum, a small force of gravity, etc.

In one of the experiments of Leonard Jaffe, the lunar soil was simulated by crumbled samples of olivine basalts contained in the craters of volcanos on the Earth. It was found that the static load-carrying capacity of the rock powder in a vacuum (10^{-6} mm Hg) is the same as in the air, and only depends on the packing density of the powder. It changes from 0.15 kgf/cm^2 for loose soils up to 7 kgf/cm^2 for dense soils. The dynamic strength of dry basalt powder in a vacuum is less than in air for loose soil, and greater than in air for a dense soil. It also strictly depends on the packing density of the powder. The thermal conductivity of basalt powder in a vacuum is 100 times lower than in air, and corresponds to the generally assumed values for the thermal conductivity of the lunar surface.

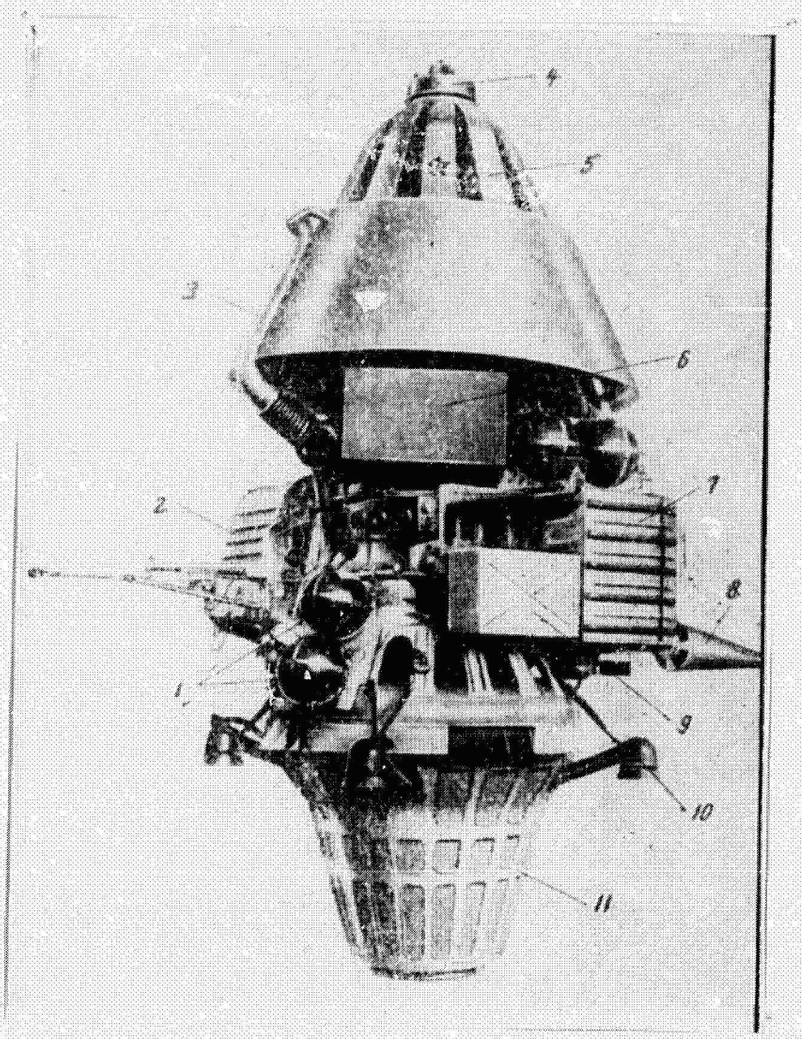


Figure 12. Automatic Station "Luna - 12" - the Third Soviet Artificial Lunar Satellite Injected into a Selenocentric Orbit at 20 Hours 47 Minutes World Time, October 25, 1966. One of the Purposes of this Station was to Obtain and Transmit to the Earth Photographs of Individual Sections of the Lunar Surface made at a Close Distance. Following are the Details of the Station: 1 - Gas Tanks for the Auxiliary Sections of the Astro-Orientation System. 2 - Phototelevision Device; 3 - Radiator of the Temperature Control Systems; 4 - Radiation Meter; 5 - Instrument Compartment; 6 - Chemical Battery; 7 - Optical-Mechanical Unit of the Astro-Orientation System; 8 - Antenna; 9 - Electronic Unit of the Astro-orientation System; 10 - Controlling Engines; 11 - Retropropulsion Unit.

The influence of the acceleration of the force of gravity upon the mechanical properties of the soil was analyzed in experiments of Galidzhan. A theoretical investigation of this problem fosters the conclusion that the strength of

loose, compressed soil must not depend on the force of gravity. At the same time, the strength of dense, noncompressed soil, which is like wet sand, must be directly proportional to it. This was verified experimentally for values of the acceleration of the force of gravity from 0.1 to 3 g by means of a device carried on the spacecraft. A lead shot, wet sand (incompressible soils) and finely crushed pumice (compressed soil) with particle dimensions of 3, 0.3 and 0.04 mm, respectively, were used as soil models. The results derived from these experiments substantiated the theoretical conclusion that for one and the same insertion into the soil the applied force was directly proportional to the acceleration of gravity in the case of the shot and the sand, and did not depend upon it in the case of the crushed pumice.

Finally, a very extensive group of studies have been devoted to the simulation of impact craters. An analysis of the form of the craters, depending on the target material and shell material, also made it possible to understand the nature of the lunar soil (Figure 11). Artificial craters were compared with lunar craters by means of large-scale photographs of the lunar surface. Figure 12 shows the third Soviet artificial satellite of the Moon -- the automatic station "Luna-12", which carried photographic equipment on-board.

It is not possible to study the microstructural characteristics of the lunar soil separately from the problem of the origin and development of the lunar crust as a whole. Experiments which have been performed on the artificial satellites of the Moon have made an enormous contribution to solving these problems.

The first artificial satellite of the Moon -- the Soviet "Luna-10" -- carried valuable information to the Earth regarding the intensity and spectral composition of the gamma-radiation of lunar rocks.

As is well known, the Earth's crust consists of rocks which are saturated to a certain extent with radioactive substances emitting gamma rays. Uranium, thorium, and the radioactive isotope of potassium predominate among the radioactive elements on the Earth's crust. The largest amount of thse elements is /15
contained in granites, basalts which are poorer in them. A comparison of the intensity of gamma-radiation from the decay of natural radioactive elements on the Moon with data derived from recordings on the Earth indicates a concentration of radioactive elements in lunar rocks which is close to that of rocks on the Earth having a basic composition (like basalts). The possibility is not excluded of rocks having ultrabasic composition (meteorite material) occurring on the surface of the Moon. No significant difference in the level of gamma-radiation intensity has been observed above the lunar seas and continents.

Several years ago, Academician A. P. Vinogradov advanced the well-known theory of "zone melting". This theory comprehensively explains the mechanism underlining the observed stratification of rocks in the depths of the Earth: the crust is comprised of a low-melting fraction, and the underlying mantle is formed of a high-melting fraction. Geochemists assume that such processes have taken place on the Moon, only the material was insufficiently separated. It is possible that lunar continents are areas of "untouched" primary matter. A comparison of the structure of the Earth's crust and the crust of the Moon,

which is not subjected to erosion by the atmosphere, the hydrosphere, and living organisms, presents scientists with an unusual opportunity for peering into the past of the Earth, and penetrating to great depths of the Earth.

Such are the inscrutable paths of science. Penetrating the infinite reaches of cosmic space, studying the galaxies which are separated from us by several billions of light years, man obtains information on the internal structure of the planet on which he lives. Samples of rocks have only been obtained from depths of 6 - 7 kilometers -- these are the records for boreholes on the Earth. Nevertheless, flights to the Moon suggest that valuable secrets regarding the structure of the depths of our planet will soon be revealed.

It is assumed that the distance from the Earth to the Moon increases with the passage of centuries. From an astronomical viewpoint, this is most likely valid. However, we individuals of the space age can assert with complete validity that the Moon becomes immeasurably closer to us with each new space experiment.

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Photographic Map of the Visible Side of the Moon. The Arrow Indicates the Region in which the Soviet Automatic Station "Luna-13" Landed on the Moon.